Low Cost Zinc Sulfide Missile Dome Manufacturing

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Abstract

The latest advancements in missile seeker technologies include a great emphasis on tri-mode capabilities, combining Long Wave Infrared (LWIR), Semi-Active Laser (SAL), and Millimeter Wave (MMW) in a small 7-inch diameter missile. Dome material selection for these tri-mode missiles is very narrow with multispectral zinc sulfide as the most common blank material. The limited supply base, long lead times, and high cost of multispectral zinc sulfide is a major issue for missile programs with dual and tri-mode seekers utilizing LWIR along with SAL capabilities. In some cases, the missile dome can comprise as much as 40% of total missile cost.

In recent years, there has been a strong emphasis on addressing affordability and manufacturing during Army Science and Technology (S&T) efforts to significantly reduce the life-cycle cost of missile systems. Studies show that applying design for manufacturing and affordability principles during the S&T phase of development yields several benefits: robust product design, mature critical manufacturing processes, earlier product presentation, enhanced product quality, and lower total costs. The Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) is leading the push for affordable technologies in Army Science and Technology (S&T) programs. An Affordability and Manufacturing Engineering Team has been established to work with Army S&T Program Managers to establish unit production cost goals, promote affordability as a major factor of preliminary analyses of alternatives, and address cost drivers concurrently with system performance.

The Affordability and Manufacturing Engineering Team has recently begun a 4-year Army Technology Objective – Manufacturing (ATO-M) Program entitled, “Low Cost Zinc Sulfide Missile Dome Manufacturing” to address zinc sulfide dome affordability and producibility. The program objective is to develop and demonstrate advanced manufacturing methods and processes that will provide a capability to produce affordable windows and domes for the new generation of multi-mode seekers for missiles, munitions and surveillance systems. The effort will take an in-depth look at the entire multispectral zinc sulfide dome manufacturing process, and optimize it for reduced cycle time and manufacturing cost. The current zinc sulfide (ZnS) chemical vapor deposition (CVD) process will be evaluated to develop ways to significantly reduce process variability, while producing favorable transmission properties. In addition, the hot isostatic pressing process will be assessed for possible elimination or alteration of this step. Post-processing steps such as dome grinding and polishing will also be studied for further reduction of cycle times, lower cost, and improved lead times.

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In conclusion, the new Army ManTech Program "Low Cost Zinc Sulfide Missile Dome Manufacturing" is currently addressing advanced manufacturing methods for lower unit production cost of multispectral zinc sulfide domes. While Dome Program personnel are still working out some of the details of the program, the objectives and planned improvements have been provided along with a program schedule and potential transitions to current DoD programs. The recent emphasis on development of affordable tri-mode seeker technologies has also been discussed. The AMRDEC Affordability and Manufacturing Engineering Team anticipates great successes on this program, and plans to take every opportunity to present these successes to achieve the widest possible dissemination to the DoD community.

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Background

The US Army Manufacturing Technology (ManTech) Program supports the development and implementation of advanced manufacturing technologies for the production of Army Material. This is accomplished through large projects that can support multiple systems or programs. These are typically 3 to 5 years in length with a funding breakdown of $1M to $3M annually. There are five main investment areas: aviation systems, armor and armaments, sensors, electronics and power systems, and precision munitions. Among other thrusts, the precision munitions area focuses on manufacturing technologies for missile seeker domes. In FY08, the Affordability and Manufacturing Engineering Team of the Manufacturing Science and Technology Division in AMRDEC launched a new ManTech program in support of this investment area, the "Low Cost Zinc Sulfide Missile Dome Manufacturing" Program. This program is focused on the development and demonstration of advanced manufacturing methods and processes that will provide a capability to produce affordable multi-mode windows and domes for the new generation of sensors for missiles, munitions, and surveillance systems.

Affordability in Science and Technology

The "Low Cost Zinc Sulfide Missile Dome Manufacturing" Program, hereinafter referred to as the Dome Program, was begun as a result of a strong emphasis for more affordable technologies within the Army Science and Technology (S&T) community. After unaffordable technologies caused the cancellation of some programs, Army S&T Program Managers began building affordability and manufacturing readiness strategies into their programs at the beginning of technology development to help ensure technology transition. These strategies were set forth in order to achieve several goals. One is robust product design with enhanced product quality. Affordability strategies are not intended to limit performance, but rather to achieve the best balance between cost, schedule, and performance. Army S&T Programs are now developing more robust technologies at a more affordable cost. Another goal focuses on mature critical manufacturing processes. This includes design for manufacturing and assembly and early manufacturing readiness assessments. By conducting and updating manufacturing readiness assessments at each stage of technology development, manufacturing goals are identified and planned prior to each milestone review. The final goal is earlier product presentation with lower total costs. S&T programs can not transition technologies that are not affordable and producible. The earlier that cost and manufacturing readiness goals are achieved, the earlier the product will be available for transition to the target Army or DoD program.

In FY03, an Affordability and Manufacturing Engineering (AME) Team was established in AMRDEC to work directly with Army S&T Program Managers to implement these affordability and manufacturing readiness strategies in each S&T Program. Currently the AME Team provides functional support to many different Army Missile S&T Programs. AME activities conducted on these programs in parallel with design and development efforts are yielding encouraging preliminary results of significant performance enhancements at equal or lower unit costs compared to baseline subsystems. The AME Team also pursues and executes Army ManTech Programs in order to develop advanced, affordable manufacturing processes for S&T technologies. Current AME efforts continue to play a large role in successful technology transitions.

Tri-Mode Seeker Domes

In recent years within the DoD, there has been an emphasis on development of missile seekers with tri-mode capabilities, transmission in three different wavelengths for operation of a Semi-Active Laser sensor, a Millimeter Wave system, and an Infrared system. This is due to new requirements for enhanced target tracking, autonomous target engagement, minimal collateral damage, and all weather performance. Depending on the type of infrared system, selection of dome materials for these seekers can be very limited. For a tri-mode seeker with a long-wave infrared system, multispectral zinc sulfide is the most common dome material used. Multispectral zinc sulfide exhibits good transmission properties in all three modes and has adequate mechanical properties for some uses; however, it also includes high unit production costs when compared with other seeker subsystems. With the current emphasis on providing more affordable technologies, missile programs have strict allowances for unit cost of each major subsystem. New missile seeker technologies must have increased performance at the same or lesser unit production cost than yesterday's counterparts. In the past few years much effort has gone toward reducing costs of electronics and other seeker components, which now positions tri-mode domes at the top of seeker cost drivers. In some cases multispectral zinc sulfide domes can account for up to 50% of the total seeker cost. This percentage must be improved upon for future programs.

There are several driving factors for high cost of multispectral zinc sulfide domes. One major factor is only a mere handful of suppliers exist around the world which manufacture multispectral zinc sulfide in the size, shape, quality, and quantity that is needed by the DoD for missile domes. For DoD programs which have made a commitment to utilizing US suppliers only, the supply base is extremely limited with only one or two suppliers to choose from. Another factor is the long lead time associated with production of multispectral zinc sulfide domes, which is partially related to low volume production quantities. These factors force the suppliers to allocate only a small amount of their equipment/time for multispectral zinc sulfide dome production. The equipment must be used for higher volume/higher profit zinc-based materials, allocating for zinc sulfide dome production only when a sufficient order quantity is reached. Zinc sulfide production requires several tedious, lengthy manufacturing processes, each requiring different personnel expertise. These will be addressed further in the following paragraphs. Another factor is high material costs. The hydrogen sulfide used in the chemical vapor deposition process is highly toxic and must be handled with costly security measures in place. In addition, the hot isostatic press process requires domes to be wrapped in costly platinum foil, with limited reuse of the foil. The final factor revolves around the chemical vapor deposition process. Different spots in a chamber may yield different dome purities, causing scrap and yield issues.

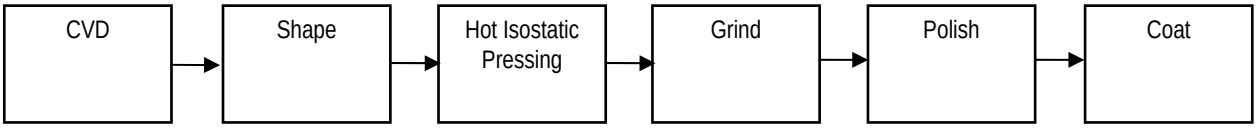
Planned Improvements

In order to address the issues with zinc sulfide dome cost and manufacturing, the AME team proposed the "Low Cost Zinc Sulfide Missile Dome Manufacturing" Program to Army ManTech in FY07. The program was approved, and was begun in FY08. This program is a 4-year, $8 Million effort with the following objectives:

- Improved processes for reduced variability resulting in high purity dome blanks
- Reduced cycle times and increased throughput
- Post processing optimization to obtain desired transmission and strength properties

– Reduced cost at each level using manufacturing science and technology

The goal is to make improvements at each level of the manufacturing process below.



The zinc sulfide domes are first "grown" in a chemical vapor deposition chamber through the introduction and mixing of zinc and hydrogen sulfide. Dome Program personnel are currently considering several possible chemical vapor deposition process improvements. There is the possibility of raw material introductions, study of chamber reactions/time in chamber, yield improvements and reduction of inclusions due to dust. The next step in the manufacturing process, the shaping of the dome blank, will also be addressed to select the most optimal tooling, reduce tool wear, control critical dimensions, minimize cutting damage, and minimize shaping cycle time.

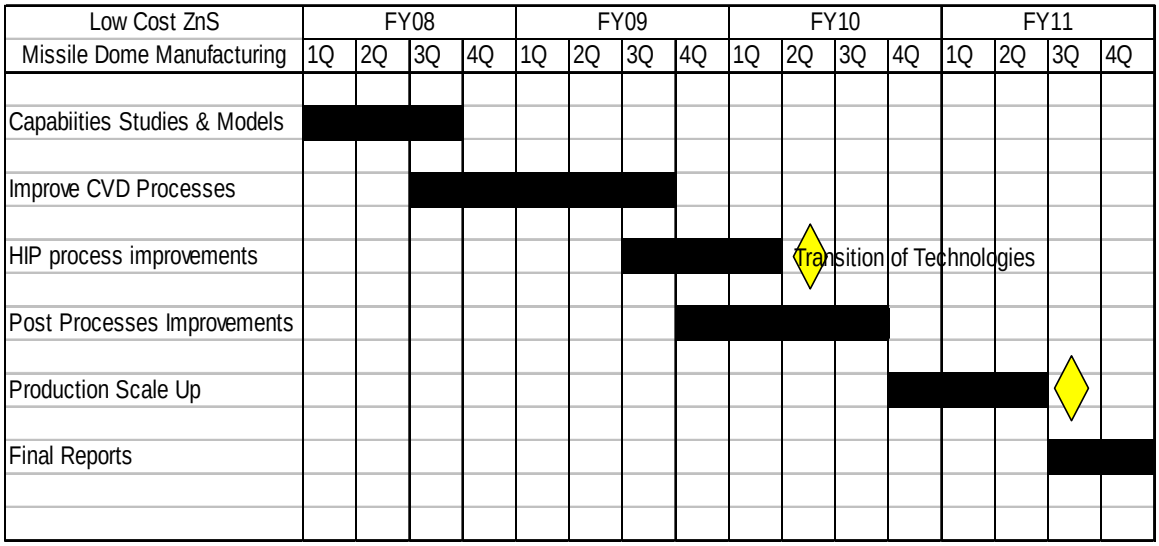
For the next stage, the dome blanks are wrapped in a metal foil, which acts as a catalyst, and are sent through a hot isostatic pressing process in order to convert the zinc sulfide blanks to a water-clear, multi-spectral material. Currently platinum foil is the best catalyst material. There is at present very little information regarding the reasons that platinum best facilitates the conversion of the zinc sulfide blank into a transparent, colorless multispectral material and other metal foils do not achieve the same outcome. Under the Dome Program, the HIP process will be assessed for clarification on this issue. The planned improvement for the HIP process is to experiment with new catalyst materials as a function of temperature and pressure to determine if there is a less expensive material that can be used. Another goal is to determine the optimal time for the improved process, possibly reducing the time the domes are in the HIP chamber. Oftentimes with such low production quantities, zinc sulfide domes are HIP-ed along with other, thicker materials and must therefore be in the chamber for longer than would be required for a batch of domes only. One concern is the negative effects that longer HIP cycle times may have on the domes. Although these negative effects are currently unknown, Dome Program personnel hope to identify and address them during the assessment/improvement of the HIP process.

The domes are then ground and polished. Improvements to the grinding process include reduction of tool wear and maximization of grinding efficiency as well as reduced cycle time. For the polishing step, in addition to reduction of tool wear, the goals will be to lower the sub-surface damage, control surface exactness, and reduce surface roughness. Finally, the polished domes must be coated with an anti-reflection coating. The planned improvements here are better control of thickness and density, better adhesion, minimization of residual reflection, and minimization of the number of layers required for optimal performance.

Transitions

Shown below is the proposed schedule for these improvements. These improvements are scheduled to be transitioned to the Army's Non Line of Sight – Launch System (NLOS-LS) Program in late FY10. Other programs which will potentially be able to take advantage of the Dome Program improvements are the Air Force's Small Diameter Bomb II Program and the Army's Mid Range Munition Program. In addition, the post processing improvements addressed

in this program may have applications to other dome/optics materials. At the conclusion of the Dome Program, results will be documented and assessed for potential benefits to other programs.



The AME Team will continue to pursue future ManTech investments to address new manufacturing technologies for other, newer optical materials in order to ensure the lowest cost and highest performance. There are currently many Small Business Innovation Research (SBIR) projects that are developing these new materials and examining them for potential applications. ManTech funding would enable smooth transitions to DoD programs. Continued tri-service involvement is key. The overall goal is to support the rapid transition of low cost missile technologies to the warfighter.

Conclusion

In conclusion, the new Army ManTech Program "Low Cost Zinc Sulfide Missile Dome Manufacturing" is currently addressing advanced manufacturing methods for lower unit production cost of multispectral zinc sulfide domes. While Dome Program personnel are still working out some of the details of the program, the objectives and planned improvements have been provided along with a program schedule and potential transitions to current DoD programs. The recent emphasis on development of affordable tri-mode seeker technologies has also been discussed. The AMRDEC Affordability and Manufacturing Engineering Team anticipates great successes on this program, and plans to take every opportunity to present these successes to achieve the widest possible dissemination to the DoD community.

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